Flow Over Rough Topography: Eddy Generation and Effects

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LONG-TERM GOAL

I would like to be able to predict the times and places where there is significant exchange of water between the ocean interior and the continental slope/shelf boundary layer.

OBJECTIVES

The sloping margins of ocean basins typically have enhanced tidal currents and turbulence. These may be important to local biological productivity, global mixing of ocean stratification, and the dynamics of coastal currents. Much progress has been made in the last decade in understanding rotating, stratified boundary layers on plane slopes (MacCready and Rhines 1991, 1993, Garrett et al. 1993). A very important current problem is the rate at which fluid in the boundary layer is exchanged with the interior, for without this exchange boundary effects have little impact. The physics of this exchange are thought by many to be tied to regions of "rough topography" such as headlands, canyons and other features, particularly when there are strong tidal currents present to drive flow across the terrain. My objective is to understand some of the basic physical mechanisms by which rotating, stratified tidal flow along a "rough" slope can exchange boundary layer fluid, or momentum (though internal waves or quasi-horizontal eddies) with the interior.

APPROACH

This work is also supported by the SECNAV/CNO Chair and Scholar award made to Mike Gregg and myself (N000149711053), allowing a range of approaches. I use the Hallberg Isopycnic Model for numerical simulations. My postdoctoral researcher, Geno Pawlak, uses laboratory experiments with configurations similar to the numerical model, but is able to push the range of topographic steepness and irregularity much further that the numerical modeling allows. Finally, in collaboration with Chris Garrett and Richard Dewey at the University of Victoria, we have an ongoing field program in the Strait of Juan de Fuca. We use arrays of moored current (Acoustic Doppler Current Profiler) and density (Thermistor-Chain) instruments to measure wave and eddy generation in this large, strongly tidal channel. These data are being analyzed by Wayne Martin, a graduate student.

WORK COMPLETED

The numerical model was modified to include tidal forcing and Lagrangian floats. About a dozen numerical experiments have been completed. A new parallel computer which will be online on the next month will speed the computations significantly.

Geno has completed many lab experiments, and analyzed the PIV (Particle Image Velocimetry) data.

Instruments were deployed and recovered successfully in the Strait of Juan de Fuca for 4 weeks (Summer 1998) and 7 weeks (Summer 1999). The 1998 data are partially analyzed for eddy, boundary layer, and wave signals. The data analysis tools we develop will apply directly to the 1999 data.

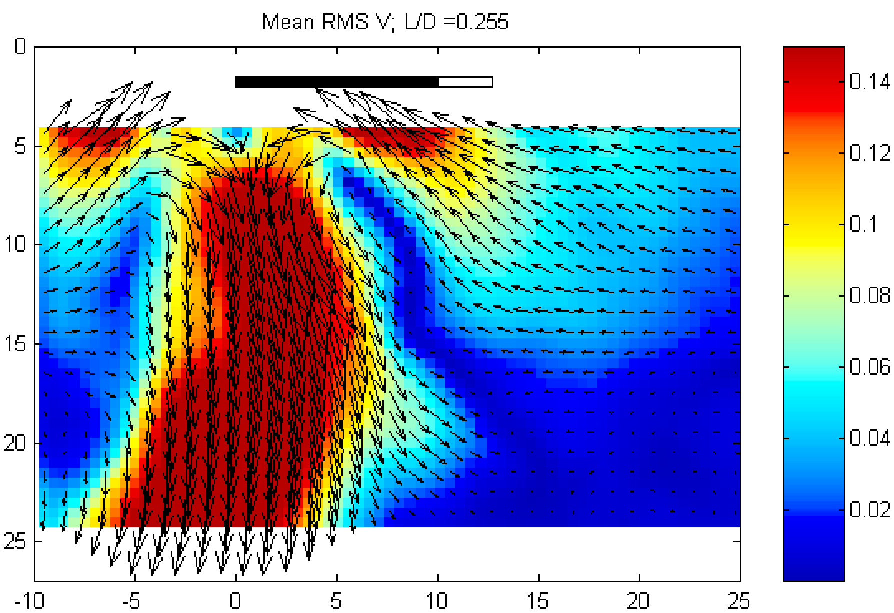
RESULTS

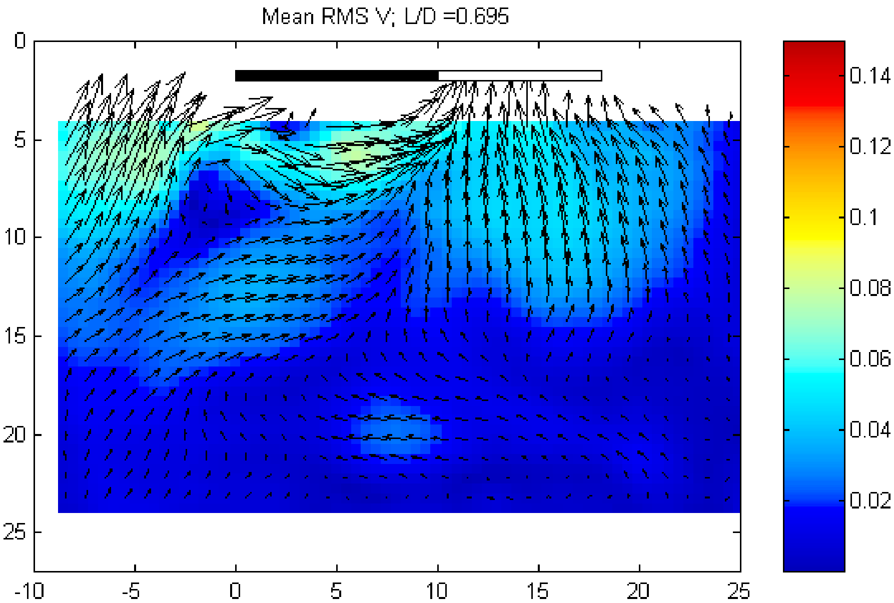
Both the laboratory experiments and the numerical simulations reveal a process by which tidal flow past a region of rough topography may enhance exchange between the boundary and interior. The quasi-horizontal separation of the flow around a ridge, on scales from 0.1 to 10 km, will create eddies rotating in both directions, depending upon the direction of the tidal flow. When the tidal excursion is small compared with the horizontal extent of the patch of rough topography these eddies interact to push fluid away from the boundary (Fig. 1a). This is the classic effect of headland eddies seen in Signell and Geyer (1990). However when the tidal excursion is comparable to or greater than the patch length the eddy interaction gives the exact opposite result: fluid from the interior is drawn in toward the patch and sent out along the slope (Fig. 1b).

1. Tracer fields from day 15 of two numerical experiments. Tidal flow is forced along a reentrant channel with a slope and ridge on the south side. The fluid is stratified, has 5 layers, and results are shown from mid-depth. The tidal excursion (stars) has a strong effect on both the strength and direction of tracer exchange between the boundary layer and the interior.

We have designed a complementary set of laboratory experiments to explore the essential mechanisms. We first consider the case of tidal flow past two-dimensional obstacles with no stratification. The idealized roughness is a patch with wave number, k, and finite extent, D. The roughness elements, provided by a set of triangular ridges, are oscillated with a sinusoidal motion along a vertical wall, simulating a tidal flow of range, L. Observations are then in the frame of reference of the mass of water moving past the rough region. The 2-D velocity field is obtained using Digital Particle Imaging Velocimetry (DPIV).

As in the numerical modeling, two distinct flow regimes are apparent. Figure 2 shows vector plots along with the RMS velocity field for either case. For long tidal excursions ($L/D > L_{crit} \approx 0.5$), a weak inflow is established in front of the obstacles, with outflows generated along the boundary outside of the rough patch. Short tidal ranges ($L/D < L_{crit}$), are marked by the formation of an outflow jet along the centerline of the obstacle motion (in the frame of reference of the moving body of water). Experiments examining the case of a single ridge show only the existence of the inflow region. This is consistent with the large tidal excursion case, since the effective width of the roughness region is zero ($L/D \to \infty$). These markedly different flow regimes have been reconciled using a 2-D vortex hypothesis.





2. Mean experimental velocity fields for the two contrasting regimes for tidal flow along an isolated region of roughness. The view is from above in a frame of reference fixed with the moving mass of water. The obstacles are located at the top of each field. The color field represents the rms velocity. The black bar above illustrates the half-width of the roughness region and the white bar represents the tidal excursion.

Results from numerical modeling agree qualitatively with the experimental observations. Hence we expect that these mechanisms persist regardless of slope and stratification. Rotation effects will be included in upcoming numerical modeling.

IMPACT/APPLICATION

Our proposed eddy mechanism for tidal "expulsion or attraction" of fluid near a region of rough topography on a slope could be useful for understanding and predicting how the ocean interacts with the continental margin.

TRANSITIONS

Kurt Polzin (WHOI) and I are convening a special session on Flow Over Rough Topography at the American Geophysical Union Ocean Sciences meeting in San Antonio, January 2000. Three of the presentations in that session relate to this work.

RELATED PROJECTS

1 – LuAnne Thompson (UW) is doing laboratory and numerical experiments on flow past irregular slopes, but at larger scale where rotational effects are important. Her results should provide a useful endpoint to ours.

2 – Eric Kunze (UW) has made measurements near Monterey Canyon which can reveal vorticity-carrying horizontal eddies. We hope to compare his observations with numerical simulations done at a similar scale.

3 – Mike Gregg (UW/APL) is analyzing coastal turbulent mixing. We work together through the SECNAV/CNO Chair-Scholar Award.

4 – Chris Garrett (U. Vic.) leads the effort to make observations in the Strait of Juan de Fuca.

REFERENCES

Garrett, C., P. MacCready, and P. B. Rhines 1993: Boundary Mixing and Arrested Ekman Layers: Rotating, Stratified Flow Near a Sloping Boundary, *Ann. Rev. Fluid Mech.*, **25**, 291-323.

MacCready, P., and P. B. Rhines 1991: Buoyant inhibition of Ekman transport on a slope and its effect on stratified spin-up, *J. Fluid Mech.*, **223**, 631-661.

MacCready, P., and P. B. Rhines 1993: Slippery Bottom Boundary Layers on a Slope, *J. Phys. Oceanogr.*, **23**, 5-22.

Signell, R. P., and W. R. Geyer, 1990: Numerical simulation of tidal dispersion around a coastal headland. Residual currents and long-term transport, R. T. Cheng, Ed., Springer-Verlag, 210-222.